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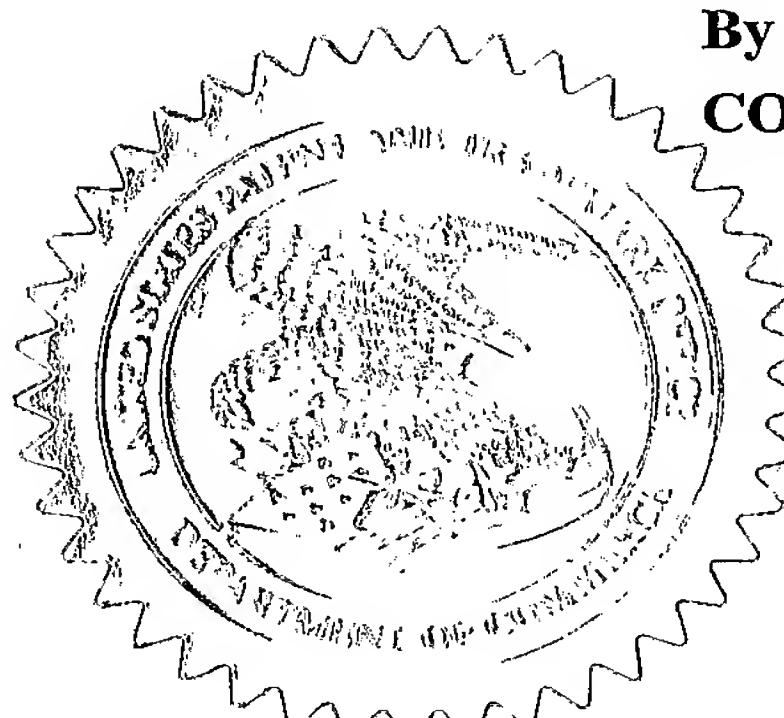
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APPLICATION NUMBER: 60/530,909

FILING DATE: December 22, 2003

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**PROVISIONAL APPLICATION FOR PATENT COVER SHEET**

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. \_\_\_\_\_

| INVENTOR(S)   |                        |   |  |     |               |
|---|------------------------|---|--|-----|---------------|
| Given Name (first and middle [if any])  | Family Name or Surname | Residence<br>(City and either State or Foreign Country) |  |     |               |
| AVIV<br>DEKEL   | TZIDON<br>TZIDON       | TEL-AVIV<br>HOD HASHARON                                |  |     |               |
| Additional inventors are being named on the _____ separately numbered sheets attached hereto  |                        |   |  |     |               |
| TITLE OF THE INVENTION (500 characters max)   |                        |   |  |     |               |
| High Precision Wide-Angle Electro-Optic Guidance System   |                        |   |  |     |               |
| Direct all correspondence to: CORRESPONDENCE ADDRESS  |                        |   |  |     |               |
| <input type="checkbox"/> Customer Number: _____   |                        |   |  |     |               |
| OR  |                        |   |  |     |               |
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| Country ISRAEL  |                        | Telephone   | 972-9-7450108                                  | Fax | 972-9-7450110 |
| ENCLOSED APPLICATION PARTS (check all that apply)   |                        |   |  |     |               |
| <input checked="" type="checkbox"/> Specification Number of Pages 9   |                        |   | <input type="checkbox"/> CD(s), Number _____   |     |               |
| <input type="checkbox"/> Drawing(s) Number of Sheets _____  |                        |   | <input type="checkbox"/> Other (specify) _____ |     |               |
| <input type="checkbox"/> Application Date Sheet. See 37 CFR 1.76  |                        |   |  |     |               |
| METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT  |                        |   |  |     |               |
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| <input type="checkbox"/> A check or money order is enclosed to cover the filing fees.   |                        |   | 80   |     |               |
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[Page 1 of 2]

Date 15-DEC-2003

Respectfully submitted,

SIGNATURE 13.3 13

REGISTRATION NO. \_\_\_\_\_

TYPED or PRINTED NAME DEKEL TZIDON

(if appropriate)  
Docket Number: \_\_\_\_\_

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## High Precision Wide-Angle Electro-Optic Guidance System

Version 2.0 December 12, 2003  
© Aviv Tzidon and Dekel Tzidon

### 1. Field of invention

This invention relates to automatic guidance of mobile platforms for purposes like docking, air refueling, taxiing and landing.

### 2. Background

The existing relative navigation aids are within the accuracies of few meters, and the more sophisticated systems have even sub-meter resolution.

The position signal (at low altitude changes in side wind influence heavily the UAV position) is of the same order of magnitude as the noise (the error of the calculated velocities caused from position error multiplied by the sampling rate).

Today most of the UAV takeoff and landing are human assisted; an external pilot that stands near the runway sees the vehicle and controls it through a remote control.

The proposed invention provides more accurate way to detect a moving platform position thus eliminating the need for external pilot

### 3. Objects and advantages

The object of this invention is to provide a guiding system that will allow the guided mobile platform to perform critical maneuvers, like docking and landing, automatically.

A guidance light beacon with precise angle location encoded in it enables a moving object equipped with light detectors to calculate accurately its position relative to the runway's centerline, and consequently guide the onboard autopilot to perform safe and accurate landing or take-off even in harsh weather conditions.

## 4 Description

### 4.1 General

The proposed system has two main parts:

1. One or more light beacons located in known positions, (e.g. end of a runway)
2. One or more electro-optic sensors, mounted on the mobile platform.

The embodiments describe systems that allow the mobile platform to accurately detect two parameters:

1. The azimuth angle with respect to a predefined direction, like runway,
2. The range to a predefined point, like the runway end.

Additional parameters, like elevation angle, can be detected as well by duplication of beacons or sensors with other spatial orientation.

There are two categories of embodiments:

1. A smart beacon that encodes the azimuth angle in a certain characteristic of its beam, combined with a sensor on the mobile platform capable of detecting this characteristic and henceforth detecting the azimuth angle,
2. A simple beacon with an array sensor capable of detecting angle of incidence on the mobile platform.

In both cases the beacon beam is shaped to cover the angular sector of interest, both in elevation and in azimuth.

### 4.2 Embodiments with smart beacon

#### 4.2.1 Beacon system consisting of two scanning beams

In this system, the angular information is encoded in the time difference between the arrivals of two scanning beams to the electro-optical sensor on the mobile platform.

There are several ways to do it; one of them is illustrated below.

Consider a beacon system consisting of two scanning light beams, which scan a common angular sector of interest. One beam scans the sector from left to right, and the other from right to left. Both scans have the same period and phase. The two occurrences in which the two beams hit the sensor are illustrated in Figure 1. This illustration shows a scenario of a landing aircraft positioned at an angle  $\beta$  with respect to the landing runway center. Beams A and B are the left-to-right and the right-to-left scanning beams respectively. Subfigures (A) and (B) show the occurrences of arrival of beams B and A respectively on the electro-optical sensor mounted on the airplane. Since the airplane is located in the right sector, beam B hits it first. Let us denote the times of arrival of beams A and B by  $\tau_A$  and  $\tau_B$  respectively, measuring from the scanning cycle start, and the angular scanning velocity of the beams by  $\omega$ . The following relations exist:

$$\tau_A = (\alpha + \beta)/\omega,$$

$$\tau_B = (\alpha - \beta)/\omega,$$

Therefore the angle  $\beta$  can be derived from the following relation:

$$\beta = \omega(\tau_A - \tau_B)/2$$

The angle  $\beta$  is positive for the right sector, and negative for the left sector. In order to determine the sign of  $\beta$ , the sensor must discriminate between beams A and B. This can be accomplished in several ways.

One way to achieve the discrimination is to build the electro-optical sensor from two receivers. If the apertures of the two receivers are displaced horizontally, it is possible to determine the scan direction by the order of arrivals on these receivers.

Another way to discriminate between the two beams is by using beams of different light intensities. The discrimination between the two beams is achieved by comparing the appropriate sensor's responses.

Alternatively, it is possible to differentiate the two beams by a certain characteristic, like polarization or wavelength. Mounting a suitable optical filter in front of the receiver aperture will make each receiver sensitive to a beam with the corresponding characteristics only.

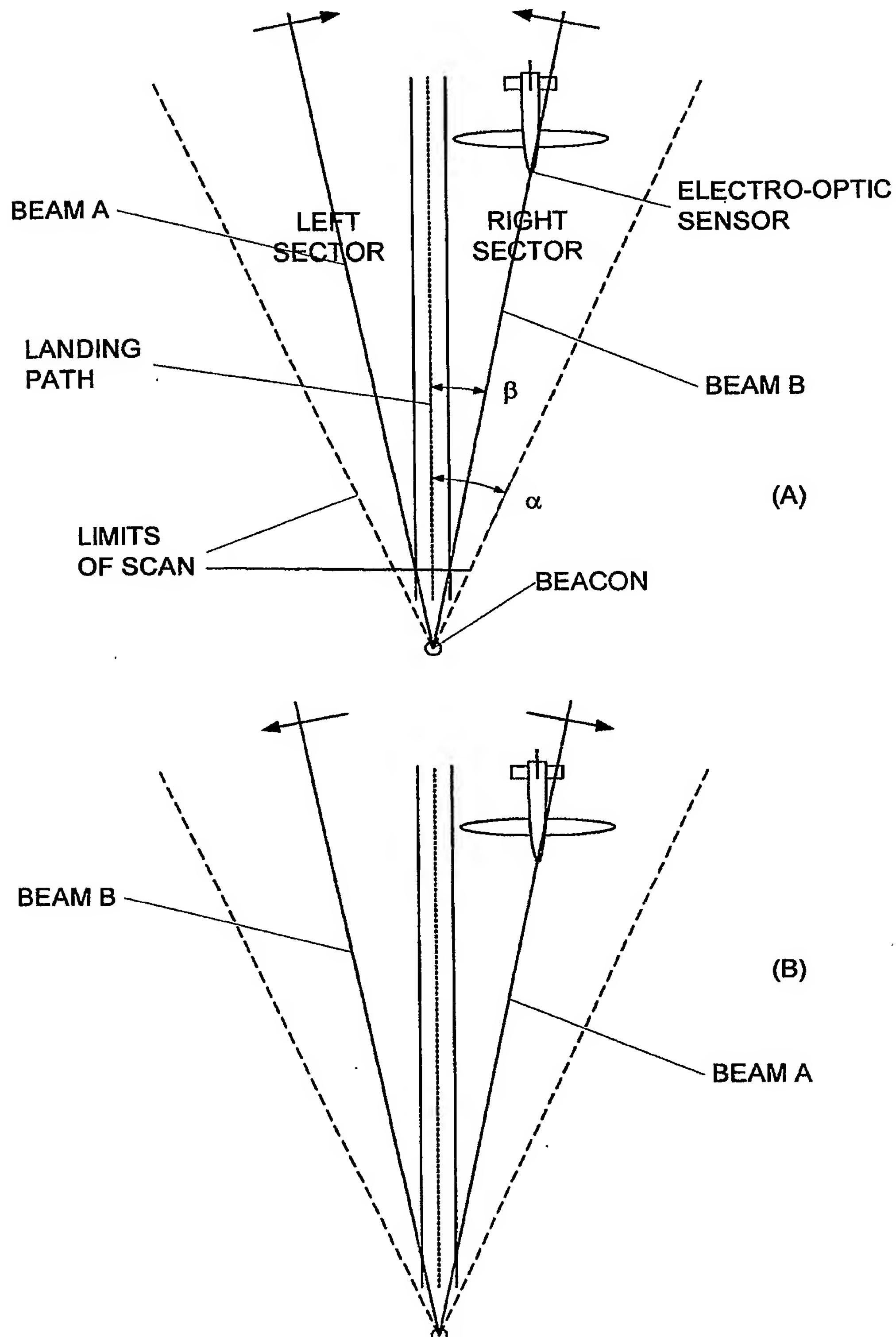


Figure 1: Illustration of beam arrival occurrences

There are several ways to encode the angular information in the times of arrival of the two scanning beams. For instance, one can use two beams with different angular scan velocities.

The range can be evaluated using two electro-optical sensors mounted apart as far as possible, e.g. at the far ends of the aircraft wings.

Let us denote the times of arrival of one of the beams on the two electro-optical sensors by  $\tau_1$  and  $\tau_2$ . Then the following relation exists:

$$R = L/(\omega * (\tau_1 - \tau_2))$$

where  $R$  is the distance to the beacon. If the plane is headed precisely towards the beacon, and the wings are horizontal, then  $L$  is the actual physical distance between the sensors. Otherwise,  $L$  is the length of a double projection of the radius vector connecting the sensors: first projection on the horizontal plane, and the second on a plane perpendicular to the radius vector connecting the plane to the beacon. In the general case, the length  $L$  can be computed from the known physical distance between the sensors and geometrical data derived from the plane navigation system.

#### 4.2.2 *Beacon system consisting of a beam with angularly encoded characteristic*

##### 4.2.2.1 *General*

One can use various characteristics of light in order to encode the angular information. Such as:

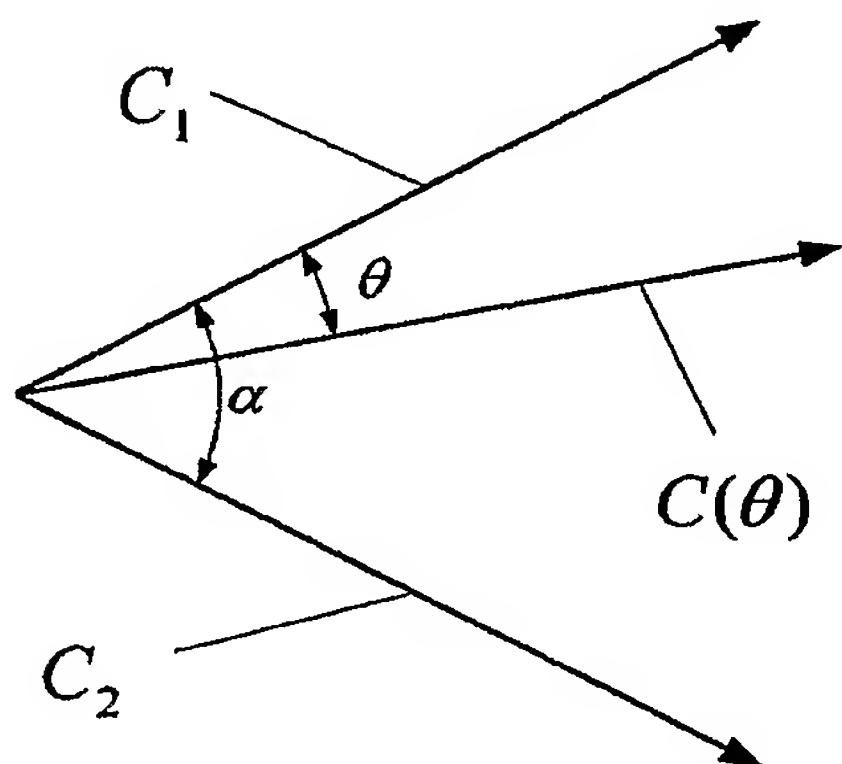
1. Wavelength
2. Polarization
3. Amplitude modulation frequency
4. Amplitude modulation contrast

The beam can be either static or scanning. In the first case, the relevant characteristic is encoded by a suitable spatial modulator, and in the second case by a time-dependent modulator synchronized with the scanning pattern.

A general way to encode the angular information by a characteristic  $C$ , as illustrated in Figure 2, is to set the values of  $C$  at an angle  $\theta$  to

$$C(\theta) = C_1 + f(\theta)C_2$$

Where  $C_1$  and  $C_2$  are certain edge values of the characteristic, and  $f(\theta)$  is any monotonous function of  $\theta$  with edge values 0 for  $\theta = 0$  and 1 for  $\theta = \alpha$ , where  $\alpha$  is the beacon beam angular extension. The corresponding sensor must be capable of measuring the value  $C$ . From this value the value of  $f$  can be derived, and from it one can derive the angle  $\theta$ .

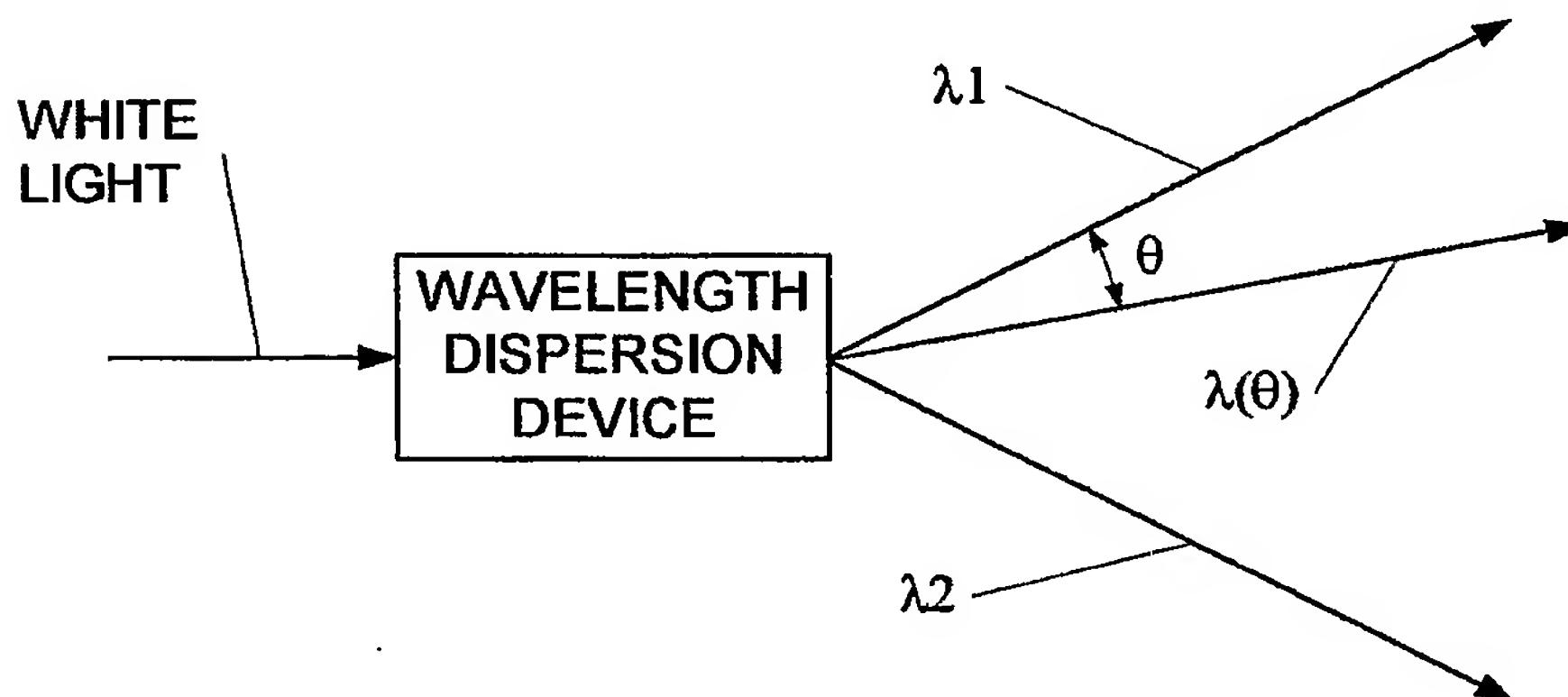


**Figure 2:** Beacon with angularly encoded characteristic

Again, two separated sensors can measure the range. Denoting by  $\delta$  the angle difference between the reading of the two sensors, the range  $R$  is given by  $R = L/\delta$  where  $L$  is as defined in paragraph 4.2.1.

#### 4.2.2.2 Wavelength encoding

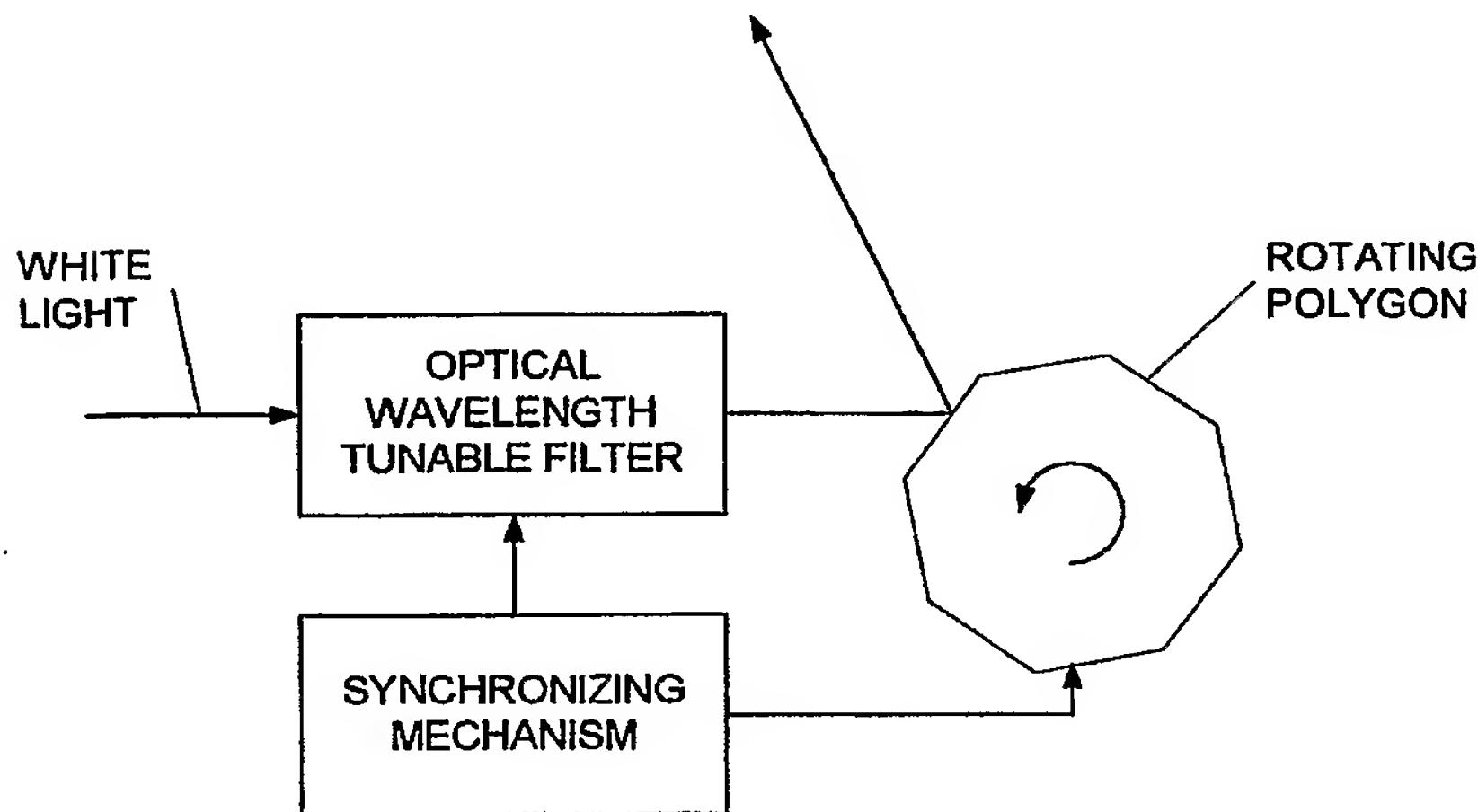
Static wavelength encoding can be achieved by dispersing a collimated white beam with a prism or a grating as illustrated in Figure 3.



**Figure 3:** Schematic illustration of static wavelength-encoded beacon

Scanning wavelength encoding may be achieved with a fast tunable optical wavelength filter, like a scanning interferometer or acousto-optic filter. This is illustrated schematically in Figure 4.

The corresponding sensor should be capable of detecting wavelength. This can be accomplished by a miniature spectrometer.



**Figure 4:** Schematic illustration of scanning wavelength-encoded beacon

#### 4.2.2.3 Polarization encoding

In polarization encoded beam each azimuthal angle is characterized by a different optical polarization state. For such encoding, one chooses two orthogonal polarization states  $P_1$  and  $P_2$  for the edge values.

The corresponding sensor should be equipped with two optical receivers, each with a polarizing filter for one of the polarization states  $P_1$  and  $P_2$ . From the ratio of the responses of the two receivers one can derive the value of  $f$ , and then the value of  $\theta$ . Static polarization encoding may be accomplished with a suitable spatial polarization modulator. Scanning polarization encoding may be accomplished with a fast elasto-optic polarization modulator.

In principle,  $P_1$  and  $P_2$  can be any pair of orthogonal polarization states. In practice it may be advantageous to use the left and right circular polarization states for  $P_1$  and  $P_2$ . This will eliminate possible error in angle measurement due to rotation.

#### 4.2.2.4 Amplitude modulation frequency

In modulation frequency encoded beam each azimuthal angle is characterized by a different amplitude modulation frequency.

The corresponding sensor should have a Fourier analyzer to measure the modulation frequency  $g$ .

Static modulation frequency encoding can be done with an appropriate spatial modulator, like a DMD device. Scanning frequency can be accomplished with a frequency-ramp (chirp) RF modulator for the optical amplitude.

#### 4.2.2.5 Amplitude modulation harmonics ratio

It is possible to modulate the beacon's beam amplitude with two harmonics at frequencies  $f_1$  and  $f_2$ , with amplitudes  $A_1$  and  $A_2$  respectively. The characteristic  $\gamma$  may be defined as the ratio

$$\gamma = A_1/A_2.$$

Static  $\gamma$  encoding can be accomplished with a suitable spatial light modulator.

Scanning  $\gamma$  encoding can be achieved by two ramped amplitude modulators.

#### 4.3 Embodiment with an array sensor

In this embodiment the beacon is a simple point light source shaped to fill the angular extensions of interest, both in azimuth and in elevation. On the other hand, the sensor mounted on the mobile platform is an array sensor capable of detecting angle of incidence information. This array detector may be a suitable electronic camera.

A single array sensor is capable of measuring the beacon radius vector direction in the coordinate system of the mobile platform. Two such sensors can evaluate also the radius vector length. If the orientation (Euler angles) of the platform coordinate system relative to the beacon coordinate system is known, then the exact position of the mobile platform may be derived. The necessary Euler angles are usually available from the platform navigation system.

## Claims

1. A light beacon that encodes the azimuth/elevation angle in a certain characteristic of its beams, combined with a sensor on a mobile platform capable of detecting this characteristic and deriving the azimuth/elevation angle.
2. As in 1, where the angle is encoded by times of arrival of two scanning beams
3. As in 1, where the angle is encoded by variable polarization states
4. As in 1, where the angle is encoded by variable light wavelengths
5. As in 1, where the angle is encoded by amplitude modulation frequency
6. As in 1, where the angle is encoded by amplitude ratio of two modulation harmonics
7. A light beacon comprising of point-source beacon and an electro-optical sensor on the mobile platform capable of detecting the direction of incidence of incoming beam